AD

EVALUATION OF ENGINE, HYDRAULIC, POWER TRANSMISSION, AND FINAL DRIVE LUBRICANTS FOR USE IN ARMY COMBAT/TACTICAL TRANSMISSIONS

INTERIM REPORT BFLRF No. 271



Ву

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Southwest Research Institute
San Antonio, Texas



Under Contract to

U.S. Army Belvoir Research, Development and Engineering Center Logistics Equipment Directorate Fort Belvoir, Virginia

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19. ABSTRACT

modifications and that an OEA-30 engine, hydraulic, power transmission, and final drive lubricant could be developed, thereby allowing the continued multipurpose use of MIL-L-2104 lubricants in Army combat/tactical ground equipment.

The development of an OEA-30 lubricant for the MIL-L-2104 lubricant s_r cification will remove two lubricant grades and eliminate the MIL-L-46167 specification from the Qualified Products List.

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EXECUTIVE SUMMARY

Problems and Objectives: Developments in engine technology leading to higher engine temperatures and increased thermal-oxidative stress on engine oils, along with new emission requirements in 1991 and 1994 have resulted in formulation changes in engine lubricants. These changes may make the lubricants less desirable as power transmission/hydraulic/final drive fluids. As a result, several manufacturers of commercial construction equipment no longer permit the use of engine lubricants in their transmission/hydraulic/final drive systems, and void the warranty if engine lubricants are used. One objective of this program was to evaluate commercial/proprietary/military engine, hydraulic, power transmission, and final drive lubricants to obtain data to support military product usage and to satisfy manufacturers' warranty requirements. Other objectives were to determine the suitability of these products in current military equipment and to reduce the logistical burden in supplying additional fluids to the field.

Importance of Project: Tactical engine lubricants conforming to military specifications MIL-L-2104, MIL-L-21260, and MIL-L-46167 are used in the engine, hydraulic, transmission, and final drive systems of combat/tactical ground equipment. This long-standing practice was introduced to reduce the logistical burden in supplying additional fluids to the field and to preclude the potentially disastrous accident of adding transmission/hydraulic/final drive fluid to the engine.

Technical Approach: The approach was to select a wide variety of commercial/proprietary/military engine, power transmission, hydraulic, and final drive lubricants and evaluate them with selected chemical/physical and bench tests. From these data, three lubricants underwent performance evaluation. These data were then used to determine the possibility of developing a new OEA-30 engine, hydraulic, power transmission, and final drive lubricant for combat/tactical ground equipment using MIL-L-2104 and MIL-L-46167 lubricants.

Accomplishments: All selected lubricants were evaluated. The results of these evaluations show that the military specification lubricants will meet the manufacturer warranty requirements with only a few upgrade modifications and that an OEA-30 engine, hydraulic, power transmission, and final drive lubricant could be developed, thereby allowing the continued multipurpose use of MIL-L-2104 lubricants for engine, hydraulic, power transmission, and final drives. Also, a continued good rapport was maintained with the equipment and lubricant manufacturers.

Military Impact: The development of an OEA-30 lubricant for the MIL-L-2104 lubricant specification will remove two lubricant grades and eliminate the MIL-L-46167 specification. This result is in compliance with Army regulations to have multiple usage and keep lubricants at an absolute minimum for combat/tactical equipment.

FOREWORD

This work was performed at the Belvoir Fuels and Lubricants Research Facility (BFLRF) located at Southwest Research Institute, San Antonio, TX, under Contract Nos. DAAK70-87-C-0043 and DAAK70-92-C-0059, for the period November 1988 through September 1991. Work was funded by the U.S. Army Belvoir Research, Development and Engineering Center (Belvoir RDE Center), Ft. Belvoir, VA, with Mr. T.C. Bowen, SATBE-FL, serving as the contracting officer's representative and Mr. M.E. LePera, SATBE-FL, serving as the technical monitor.

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- Mr. Edwin A. Frame for his technical counsel and friendship,
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I. INTRODUCTION/BACKGROUND

At the present time, engine oils conforming to Military Specifications MIL-L-2104 "Lubricating Oil, Internal Combustion Engine, Combat/Tactical Service" (1)*, MIL-L-21260 "Lubricating Oil, Internal Combustion Engine, Preservative and Break-In" (2), and MIL-L-46167 "Lubricating Oil, Internal Combustion Engine, Arctic" (3) are used in both the engines, transmissions/final drive, and selected hydraulic systems of Army ground equipment. This long-standing practice was introduced to reduce the logistical burden in supplying additional fluids to the field and to preclude the accidental and potentially disastrous effect of adding transmission/hydraulic fluids to the engine.

Recent developments in engine technology leading to higher operating temperatures, increased thermal-oxidative stress on engine oils, and new emission requirements in 1991 and 1994 have resulted in formulation changes in engine oils, which may make them less desirable as transmission/hydraulic/final drive fluids. Several manufacturers of Commercial Construction Equipment (CCE) no longer permit use of engine oils in transmissions of Commercial Construction Equipment and void the warranty if engine oil is used. A need for a separate military specification for a transmission/hydraulic fluid may exist. As a result, continued research and development in this area is critical.

The MIL-L-2104E specification requires the Caterpillar TO-2 (4) Friction Retention (Bronze) test and the Allison C-3 (5) Friction Retention (Graphite) test. Until recently, lubricants from both of these specifications could be used in the engine and powershift transmission/hydraulic systems as is allowed by MIL-L-2104, MIL-L-21260, and MIL-L-46167 specifications.

Caterpillar, Inc., which is developing a new TO-4 (6) specification for power transmission fluids, will require the use of these fluids in its transmissions only (not for engines). Caterpillar will no longer recognize the TO-2 specification for use in its transmission in 1991 as a result of a compatibility problem that had developed with fluoroelastomer material used in seals and clutch

^{*} Underscored numbers in parentheses refer to the list of references at the end of this report.

plates of Caterpillar transmissions. Caterpillar feels that to be able to deliver maximum long-term performance with both the modern engine and transmission lubricants, separate and distinct lubricants must be used.(7)

During this program, Caterpillar made the decision to no longer support TO-2 friction testing, and no longer recommends the use containing VI improvers for its powershift transmissions and final drives. In addition, the American Society for Testing and Materials (ASTM) TO-2 Surveillance Panel has voted to disband the panel. Also, Caterpillar has replaced the TO-2 Friction test with the TO-4 Friction Properties test, which uses one bronze, two fluoroelastomer, and three paper friction materials.

Allison Transmission Division (ATD) announced that the C-3 power transmission specification has been replaced by a new C-4 (8) power transmission specification and began recommending only C-4 fluids in late 1989. The C-4 specification has two Friction Retention tests. One test uses graphitic materials, and the other test uses paper composite materials. ATD plans to continue the use of engine oils in the transmissions, but it is, at the same time, introducing more fluoroelastomer material in its transmissions. The increased use of these materials could result in fluoroelastomer degradation problems similar to those experienced by Caterpillar. Therefore, ATD is developing a fluoroelastomer compatibility test in its C-4 specification. Any fluoroelastomer problems in the ATD transmissions could have a major impact on the U.S. Army, since the majority of the Army's tactical ground equipment powershift transmissions are manufactured by ATD and use engine oils as lubricants.

Also, the John Deere J20A multipurpose hydraulic/power transmission specification brake chatter test uses a paper asbestos brake material, but the John Deere construction equipment uses graphitic friction brake materials. Presently, John Deere is in the process of changing its friction brake materials.

These developments and actions require that the U.S. Army evaluate these new transmission fluids and multipurpose power transmission fluids being developed by industry to determine the acceptability of these fluids in Army combat/tactical ground equipment. The U.S. Army may

also need to develop military specifications for the procurement of power transmission fluids that will satisfy manufacturers' warranty requirements if the performance of MIL-L-2104 cannot be modified to accommodate this changing requirement.

MIL-STD-838 (9), "Lubrication of Military Equipment," and doctrine states that petroleum logistics is most effective when the number of standard fuels and lubricants is kept to the absolute minimum that will still permit the required defense posture of the U.S. Army. To keep this number at a minimum, the type and number of fuels and lubricants required to support equipment must be controlled. Thus, maximum use will be made of standard specification products in the design and provision of new vehicles and equipment.

II. OBJECTIVES

The objective of this program was to investigate commercial/proprietary hydraulic/power transmission fluids to establish criteria for supporting the use of military specification products in satisfying manufacturer warranty requirements and fully meeting equipment lubrication needs.

III. APPROACH

The performance of this work, based on previous efforts conducted in this area (10-18), consisted of the following phased program:

- · Selection of lubricants
- · Solicitation and procurement of the lubricants
- Selection of chemical/physical/bench tests
- · Test evaluation and data collection
- Select lubricants for performance evaluation tests
- Conduct performance tests.

A. Test Lubricants

Currently, a large number of proprietary multipurpose hydraulic/power transmission and final drive lubricants is available for equipment usage. Therefore, a wide variety of lubricants were selected for this program that satisfy both the manufacturers' warranty requirements and meet the needs of the Army ground/tactical equipment. To date, twenty lubricants were selected and obtained for evaluation. These lubricants were (1) commercially available and acceptable under proprietary specifications, (2) diesel engine/hydraulic/power transmission and final drive lubricants used in Army ground/tactical equipment and, (3) candidate arctic engine/hydraulic/power transmission lubricants. TABLE 1 lists the fluids/lubricants with BFLRF code and applicable specifications.

Of these 20 lubricants, six (Nos. 1 through 6) are proprietary multipurpose hydraulic/power transmission fluids, and five (Nos. 7, 8, 9, 17, and 19) are listed under MIL-L-2104 specification. Two lubricants (Nos. 15 and 16) are Caterpillar TO-4/TO-5 Heavy-Duty Powershift Transmission Oils, two (Nos. 11 and 14) are MIL-L-21260 lubricants, and one (No. 12) is a commercial CE, SAE grade 15W-40 lubricant. Also, three lubricants (Nos. 10, 18, and 20) are OEA-3C candidates, while lubricant No. 13 is a Super Tractor Oil Universal (STOU). The 20 lubricants include a wide variety of additive packages.

B. Test Selection

As shown in TABLE 2, no single common specification for hydraulic and power transmissions is used. The manufacturers of commercial construction and material-handling equipment issue and each use its own proprietary specification for hydraulic and power transmission lubricants, even though an American Society for Testing and Materials panel has developed a uniform specification for a multipurpose hydraulic/power transmission lubricant. The test pre-edures selected for this program were taken from an updated listing of the various manufacturers' requirements for hydraulic and power transmission lubricants (TABLE 3) as originally reported in Reference 14 in September 1982. These physical/chemical property and bench tests (TABLE 4) were selected because they were best suited to this program.

TABLE 1. Test Lubricants

Lube No.	BFLRF Code	Description/Specification	
1	AL-18614-L	Case/International (MHPT)	MS-1207
2	AL-18658-L	Ford/New Holland (MHPT)	M2C134
3	AL-18665-L	John Deere (MHPT)	JDM-J20A
4	AL-18669-L	John Deere (MHPT)	JDM-J20A
5	AL-18676-L	Massey-Ferguson (MHPT)	MF-1141
6	AL-18677-L	Massey-Ferguson (MHPT)	MF-1141
7	AL-18928-L	Army Qualified Product (SAE Grade 10W)	MIL-L-2104
8	AL-18927-L	Army Qualified Product (SAE Grade 30)	MIL-L-2104
9	AL-18750-L	Army Qualified Product (SAE Grade 15W-40)	MIL-L-2104
10	AL-18930-L	OEA-30 Candidate	Company A
11	AL-18955-L	Army Qualified Product (SAE Grade 10W)	MIL-L-21260
12	AL-18890-L	CE (SAE Grade 15W-40)	Commercial
13	AL-18891-L	Super Tractor Oil Universal (Engine, Transmission, Hydraulic, Gears)	STOU
14	AL-19026-L	Army Qualified Product (SAE Grade 15W-40)	MIL-L-21260
15	AL-18997-L	Caterpillar Powershift Transmission Fluid (SAE Grade 10)	TO-4/TO-5
16	AL-189∂5-L	Caterpillar Powershift Transmission Fluid (SAE Grade 30)	TO-4/TO-5
17	AL-19119-L	Allison Transmission Div. (C-4) Fluid/Army Qualified Product (SAE Grade 15W-40)	C-4/MIL-L-2104
18	AL-19392-L	OEA-30 Candidate	Company B
19	AL-19424-L	Allison Transmission Div. (C-4) Fluid/Army Qualified Product (SAE Grade 15W-40)	C-4/MIL-L-2104
20	AL-19528-L	OEA-30 Candidate	Company C

TABLE 2. Manufacturer and Lubricant Specifications

Manufacturer	Specification
Ford	ESN-M2C134-C (19)
John Deere	JDM-J20A (<u>20</u>)
Massey-Ferguson	MF-1141 (<u>21</u>)
t so International	MS-1207 (22)
Allison Transmission Div.	C-4
Caterpillar	TO-4/TO-5
Army	MIL-L-2104D SAE Grade 10W SAE Grade 30 SAE Grade 15W-40
	MIL-L-21260 SAE Grade 10W SAE Grade 15W-40
	MIL-L-46167 OEA-30 Candidate
API/SAE/ASTM	CE, SAE Grade 15W-40
Various	STOU (23)

TABLE 3. Listing of Suppliers of Hydraulic/Power Transmission Systems Fluid Requirements for Wheeled and/or Crawler Vehicles

Manufacturer Specification	Allison Chalmers PF 821	Allison Transmission C-4	Caterpillar TO-4/TO-5	J.L. Case <u>TCH145</u>	Deutz GL-4	John Deere JDM-J21A	Case/ International MS-1207
K. Vis., cSt, at 40°C	X*	X	X	NR	X	NR	NR
K. Vis., cSt, at 100°C	x	x	X	x	X	X	x
Viscosity Stability at							
98.9°C (210°F)	NR	NR	NR	x	NR	X	x
Viscosity Index	NR	NR	X	X	x	NR	x
Apparent Vis., at							
-17.8°C (0°F)	X	x	X	X	NR	X	x
-28.9℃ (-20°F)	NR	x	NR	NR	NR	NR	x
Flash Point, °C	NR	x	NR	X	NR	NR	NR
Fire Point, °C	NR	x	NR	X	NR	NR	MR
Pour Point, °C	X	x	X	X	X	X	x
Rust Protection	x	x	X	X	X	X	x
Corresion	X	x	X	x	x	x	X
Antifoam	X	x	X	X	x	NE	x
Elastomers/Rubber Compatibility	X	x	X	x	x	X	x
Compatibility w/other Oils	x	NR	x	x	x	X	x
Oxidation & Thermal Stability	X	x	X	x	X	X	x
Friction, Clutch and/or Brake	NR	x	X	x	x	X	x
Transmission Durability	x	NR	NR	NR	x	X	x
Wear Protection	X	x	X	X	x	X	NR
Toxicity	NR	NR	NR	X	NR	NR	NR
API Gravity	NR	NR	X	NR	NR	NR	NR
Aniline Point	NR	NR	NR	NR	NR	NR	x
Color	NR	NR	NR	NR	NR	NR	x
Hydraulic Performance	NR	x	X	X	X	X	x
Metals	x	x	X	NR	NR	X	NR
Neutralization Number	NR	NR	NR	NR	NR	NR	NR
Odor	NR	NR	NR	NR	NR	NR	NR
Carbon Residue	NR	NR	X	NR	NR	NR	NR
Precipitation	NR	NR	NR	NR	NR	NR	NR
Stable Pour Point	NR	x	NR	NR	NR	NR	NR
Sulfur	NR	NR	NR	NR	NR	x	NR
Phosphorus	NR	NR	NR	NR	NR	x	NR
Chlorine	NR	NR	NR	NR	NR	×	NR
Nitrogen	NR	NR	NR	NR	NR	X	NR
Water Tolerance	NR	NR	x	NR	¥	x	x
Dynamic Corresion (Sondstrand)	NR	NR	NR	NR	x	NR	NR
Cold Oil Flowability	NR	NR	NR	NR	x	NR	NR
Galvanic Protection	NR	NR	NR	NR	NR	NR	NR

^{*}X = To Be Determined.

NR = Not Required.

TABLE 3. Listing of Suppliers of Hydraulic/Power Transmission Systems Fluid Requirements for Wheeled and/or Crawler Vehicles (Cont'd)

Manufacturer Specification	Massey- Ferguson MF-1141	Minneapolis Moline 35301	Oliver/ White S-3727-B	Versatile IDM-J20A	Fiat-Allis GM-6137-M	Ford <u>M2C134-C</u>	ASTM Proposed
K. Vis., cSt, at 40°C	NR*	x	x	NR	NR	NR	NR
V. Viz., cSt, at 100°C	x	X	X	x	x	X	X
Viscosity Stability at							
98.9℃ (210°F)	X	x	NR	X	NR	X	X
Viscosity Index	X	X	NR	NR	NR	NR	NR
Apparent Vis. et							
-17.8℃ (0°F)	X	x	NR	X	X	X	X
-28.9℃ (-20°F)	NR	NR	NR	NR	x	NR	Ж
Flash Point, °C	NR	x	X	X	x	X	X
Fire Point, °C	NR.	X	NR	NR	x	X	NR
Pour Poirt, °C	x	X	x	x	NR	X	NR
Rust Protection	x	X	NR	X	x	X	X
Corrosion	x	x	X	X	x	X	X
Antiform	x	X	X	X	x	X	X
Elactomers/Rub' or Compatibility	X	X	NR	X	x	X	X
Compatibility w/other Oils	NR	X	NR	X	x	X	NR
Oxidation & Thermal Stality	x	Х	NR	x	x	X	X
Friction, Clutch and/or Brake	x	x	x	X	x	x	x
Transmission Durability	x	X	NR	x	x	x	NR
Wear Protection	X	x	NR	x	x	X	X
Toxicity	x	Y	NR	NR	x	X	NR
API Gravity	NR	X	NR	NR	NR	NR	NR
Aniline Point	NR	x	NR	NR	NR	NR	NR
Crior	NR	NR	X	NR	NR	NR	NR
Hydraulic Pr-formance	NR	NR	Nk	x	x	NR	Y
Metals	NK	NR	NR	NR	NR	X	NR
Neutralization Number	NR	x	X	NR	NR	NR	NR
Odor	NB	X	NR	NR	NR	X	NR
Carbon Residue	NR	NR	NR.	NR	NR	NR	NR
Precipitation	NR	x	NR	NR	NR	NR	NR
Stable Pour Foins	NR	NR	nR	NR	NR	NR	NR
Sulfar	NR	X	NR	NR	NR	NR	NR
Phosphorus	NR	NR	NR	NR	NR	NR	NR
Chlorine	NR	NR	NR	MR	NR	NR	NR
Nitrogen	NK	NR	NR	NR	NK	NR	NR
Water Tolerance	NR	NR	NR	X	X	NR	x
Dynamic Corrotion (Sundstrand)	NR	NR	NP	NR	NR	NR	x
Cold Oil Flowability	MA	NR	NR	X	NR	NR	NR
Galvanic Protection	NR	NR	NR	NR	NR	NR	x

^{*}X = To Be Determined. NR = Not Required.

TABLE 4. Chemical/Physical Properties and Bench Tests

- a. Viscosity at 40° and 100°C (D 445)
- b. Pour Point (D 97)
- c. Foam Tendency [D 892A + Sequence 4 (MERCON)]
- d. Copper Corrosion at 150°C (D 130)
- e. TAN (D 664)
- f. TBN (D 664)
- g. Elastomer Compatibility (Buna N, Polyacrylate, Silicon, Fluoroelastomer) ATD C-4
- h. Elemental (XRF and ICP)
- i. Nitrogen (D 4629)
- i. Tests on Selected Lubricants:
 - Viscosity at -40°C (D 455)
 - High-Temperature, High-Shear Viscosity (D 4683) (D 4628)
 - TFOUT (D 4742)
 - LUBTOT
 - ATD C-4 Pump Wear
 - ATD C-4 Friction Characteristics (Graphite)

Upon completion of the chemical/physical property and bench tests, the data were collected and tabulated. From these data, three lubricants (Nos. 10, 16, and 20) were selected in conjunction with Belvoir RDE Center for evaluation in the HT/HS Viscosity (D 4683), TFOUT (D 4742), LUBTOT (24), ATD C-4 Pump Wear and C-4 Friction Characteristics (Graphite) performance tests.

- TFOUT (D 4742) is used to evaluate oxidation stability of lubricating base oils with additives in the presence of chemistries similar to those found in engine service.
- HT/HS viscosity (D 4624) is used to measure the viscosity at or near the conditions of shear rate and temperature that will be experienced in severe service.
- LUBTOT is used to evaluate lubricant's performance in the amount of oil deposits formed on hot surfaces since excessive deposits can drastically shorten the life of power train systems.
- C-4 Pump Wear is used to measure wear characteristics of lubricants to protect pump and transmission components from excessive wear.
- C-4 Frictional Characteristics (Graphite) is used to measure the friction characteristics of power transmission lubricants on heavy-duty graphite-composite clutches.

IV. DISCUSSION OF RESULTS

The test lubricants were evaluated as they were received at BFLRF. Upon completion of the selected physical/chemical/bench tests, the test results from each lubricant were tabulated. These results are reported in TABLE 5. These results were then compared to the various proprietary and military specification for pass or fail results. Of the 20 lubricants evaluated, only five lubricants (Nos. 2, 14, 15, 16, and 19) passed all tests. The 15 failed lubricants included four failures with the copper corrosion test, six failures with the seal compatibility test, and eight failures with the foam characteristics test. The three OEA-30 candidate lubricants had two lubricants (Nos. 10 and 18) that failed both the pour point and the -40°C viscosity tests.

The results show that the lubricants that failed the copper corrosion test were lubricant Nos. 7, 8, 9, and 17. All four of these lubricants are MIL-L-2104 lubricants. No flaking was observed on any of the copper strips. MIL-L-2104, MIL-L-21260 and MIL-L-46167 specifications do not contain a copper corrosion requirement because no apparent copper corrosion problems have been observed in the field. These four lubricants also qualified as ATD C-3 fluids, which use the 100°C copper corrosion test temperature. The other MIL-L-2104 lubricant (No. 19) had passed the new ATD C-4 specification, which uses the copper corrosion test at the 150°C test temperature.

Five lubricants (Nos. 1, 8, 10, 12, and 18) failed the hardness change requirement of the total immersion test (ATD C-4). Lubricant No. 18 failed both the volume change and the hardness change of the total immersion test, and lubricant No. 20 had a borderline fail with the total immersion hardness change test. Note that lubricant Nos. 10, 18, and 20 are OEA-30 candidate grade synthetic blend lubricants; the Army synthetic lubricants (MIL-L-46167) have traditionally had problems with the seal compatibility tests.

Lubricant No. 3 failed both Sequences I and III of the foam test; four lubricants (Nos. 4, 5, 6, and 13) failed Sequences II and IV of the foam test; and three lubricants (Nos. 10, 11, and 12)

TABLE 5. Chemical and Physical Properties Test Results

, XRF**,																					
CLM*	z	0.011	0.014	0.014	0.015	0.013	0.018	0.044	0.050	0.047	0.057	0.030	0.092	0.079	0.034	0.00	0.011	0.115	0.064	0.056	0.151
	Zu	17	1381	1282	1401	1480	748	1000	1110	818	1029	1961	1356	1237	1704	290	581	1084	1234	1090	1080
	ام	2713	1149	1017	1113	1124	1068	928	1056	111	954	1219	1234	1506	1162	605	629	896	1075	985	1194
٠	Na	146	19	89	∞	∞	13	S	7	4	11	23	17	91	21	34	27	_	S	15	19
	ΞĮ	-		7	-	-	_	7	₹	7	7	₹	7	7	7	7	-	7	⊽	7	7
CP, ppm	¥	7	7	₩	7	7	10	7	7	7	60	7	7	E	7	7		7	7	7	₹
Ď	'	~		⊽		⊽	V	√ √	⊽ ~	⊽ ~		⊽		_		⊽	⊽	7	-	7	⊽
	Mg	∞	2	0	15	2	3840	1270	1368	1087	650	414	æ	Ξ	438	4	∞	840	-	483	∞
	ವ	4014	3893	3061	3799	3855	41	15	32	22	1901	1608	2212	5056	1640	3294	3241	944	2900	1798	2144
	8	7	97	7	102	₹	7	12	15	171	7	4	S	7	8	7	7	4	345	117	201
	\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	7	7	7	7	7	7	7	7	13	7	⊽	$\overline{\mathbf{v}}$	7	∇	7	7	4	4	⊽	7
TBN, D 664		5.3	12.8	10.0	11.1	10.6	13.0	6.5	6.8	8.3	6.7	6.2	8.2	9.2	7.4	5.8	7.9	6.4	5.0	6.4	6.4
TAN, D 664		1,4	2.5	2.8	2.6	2.7	2.8	2.4	2.7	5.9	5.6	3.6	2.7	3.8	3.7	1.7	1.7	3.7	2.6	24	2.5
Copper Corresion, 150°C, D 130	, , , , , , , , , , , , , , , , , , ,	113	Y 1	Y	₹1	\	1A	(4 C)	(4 C)	(4B)	₹1	13	41	18	¥1	81	18	(4A)	1A	1A	41
Pour Point, °F. D 97		-36	-31	-33	-34	-28	-29	-30	-23	-73	(40)	-30	-29	87-	-31	-33	-32	-23	(-54)	12-	-55
	40°C	1	ı	1	1	i	1	ŧ	ı	t	+	t	ı	ł	ŧ	1	l	i	26,463	ı	14,517
7, cSt,	5	107	139	152	146	134	145	111	105	133	280	119	145	130	135	101	66	149	214	13	198
Viscosily, cSt, D 445	100°C	6.27	9.26	9.89	9.47	9.12	9.43	6.61	11.04	13.80	19.70	6.47	14.52	11.31	14.59	6.19	11.57	14.58	10.46	14.03	11.01
•	40°C	39.31	58.55																		54.78
Lubricant No.		•	7	m	4	٧,	v	٦	∞	۵	2		12	13	7	13	91	17	82	61	20

[•] CLM = Chemiluminescence. •• XRF = X-ray fluorescence. () Indicates fail. + Cov'4 Lot obtain a valid viscosity at -40°C.

TABLE 5. Chemical and Physical Properties Test Results (Cont'd)

- Inputer	į											•			!		
Na	EE É	Total	Total Immersion	dia	Cycle	Trp	Trp Cycle	Fluoroc	Fluoroclastomer	tos:		Seq. II		Seq. III		Seq. IV	IV
	r G			Charle	Change	Change	Change	O Denge	Change	Slow	Senie	Blow	Yettle	Plow Blow	Settle Settle	S-Min. Blow	Sente
	∇ ⊽	+5.95	(+)	+7.42	ů,	+3.76	7	+2.19	7	0	0	8	0	0	0	æ	0
7	₽	9971+	0	+3.76	÷	+3.40	.2	+1.23	0	0	0	0	0	0	0	0	0
~	⊽	+3.12	ç	+5.48	ņ	+3.88	7	+1.57	7	9	(30)	30	0	(100)	(40)	8	0
•	⊽	+1.79	Ç	+3.96	4	+3.50	7.	+3.50	ç	0	0	(300)	(10)	0	•	(310)	140
~	⊽	+1.68	0	+4.17	ņ	+3.40	7.	+1.28	7	0	0	(072)	9	0	0	(380)	8
ø	₹	+1.60	-	+3,99	?	+3.36	7	+1.38	0	0	0	(270)	(091)	0	0	(340)	8
7	⊽ -	+2.51	*	44.69	-	+3.68	7-	+1.19	+2	0	0	20	0	0	ں	&	0
•	-	+0.86	(+)	+3.01	0	+2.23	7	+0.70	+3	0	0	2	0	0	0	20	0
۰	▽	+2.31	7	+4.02	7.	+3,44	7.	+1.04	7	0	0	8	0	0	0	8	0
0	7	+1.07	(÷)	+4.56	7-	+4.42	7.	+1.80	Ŧ	0	0	4	0	0	0	(011)	0
=	7	+5.21	0	+6.26	÷	4.43	?	+1.55	+5	0	0	\$	0	0	0	(011)	0
22	⊽	_	€.	10.0	0	+3.28	7	+1.01	+3	0	0	દ્ભ	0	0	7	(110)	0
5	₹ ₹		+5	+4.41		+2.97	ç	+0.87	7	0	0	(290)	(120)	0	o	(330)	0
ĭ	- ⊽	+4.30	0	+5.38	4	+3.38	7	+1.07	+2	0	o	0	0	0	0	0	0
5 2	₹		0	+4.48	.5	+3.78	7	+1.35	0	0	0	0	0	0	0	0	0
20	⊽	+0.12	0	+3.15	ç	+2.24	~	+0.81	7	0	0	0	0	0	0	0	0
1		+422	1	+6.02	٠	+3.39	7.	+1.21	+5	0	0	0	0	0	0	20	0
=		(-0.91)	(EE)	+3.25	7	+4.31	7	+0.75	+3	0	0	8	0	0	0	901	0
19	7	\$9"1+	Ţ	+4.16	7	+3.03	-5	+0.71	+5	0	0	0	0	0	0	0	0
R	⊽	+3.67	1	+8.32	9	+4.89	7	+2.66	7	•	0	0	0	0	0	8	•
MIL-L-2104B	e)	+0.75 to +6.75	0±5	01+ 01+	-S to 0	+1.5 to +6.5	-10 to G	•	+	×	0	150	0	ĸ	0	+	+
C-4 Acceptable Adjusted Limits	nite nite	+0.75 to +6.75	0 4 5	01+ 010+	-5 to 0	+1.5 to +6.5	-10 to 0	•	•								
C-4 and MERCON	NCC																

Not part of MIL-L-2104 specification.
 Report limits not established.
() Indicates fail.

failed only Sequence IV of the foam test. The MIL-L-2104, MIL-L-21260, and MIL-L-46167 specifications do not, as yet, have a requirement for the Sequence IV foam test.

Of the three OEA-30 candidate lubricants (Nos. 10, 18, and 27), Nos. 10 and 18 failed the pour point of -55°C with -40° and -54°C, respectively. Both of these lubricants also failed the temporary -40°C viscosity of 15,000 to 16,000 cSt maximum.

Those lubricants that failed more than one test include: Lubricant No. 8 failed two tests, the copper corrosion and the seal compatibility tests; lubricant No. 12 failed two tests, the seal compatibility and foam characteristics tests; lubricant No. 18 failed three tests, the seal compatibility and two cold temperature tests at -40°C, viscosity and pour point tests; lubricant No. 10 failed four tests, the seal compatibility, foam characteristics, and the cold temperature tests at -40°C, viscosity and pour point tests.

From the data in TABLE 5, BFLRF, in concert with Belvoir RDE Center personnel, selected lubricants Nos. 10, 16, and 20 for additional evaluation. The additional bench and performance tests included the HTHS Viscosity (D 4683), TFOUT (D 4742), LUBTOT, ATD C-4 Pump Wear, and C-4 Friction Characteristics (Graphite) tests.

Lubricant No. 10, the OEA-30 candidate, was selected even though the lubricant failed the -40°C viscosity, seal compatibility (Total Immersion), and Sequence IV Foam tests. The manufacturer has blended a candidate lubricant that has the same basic additive package as Lubricant No. 10 but with improved cold flowability, seal and foam characteristics. This new candidate will be evaluated upon receipt at BFLRF. Lubricant No. 16 is the Caterpillar TO-4/TO-5 service fill fluid and is of interest because Caterpillar no longer recommends engine lubricants or lubricants containing viscosity improvers for use in its heavy-duty powershift transmissions and in many final drive gear boxes. Lubricant No. 20 is the best OEA-30 candidate evaluated in the chemical/physical property tests. The results for the HTHS viscosity, TFOUT and LUBTOT tests are shown in TABLE 6 and again lubricant No. 20 appears to be the best.

TABLE 6. Performance Bench Tests

Lube No.	Lube Code	HTHS Viscosity at 150°C	TFOUT, min.	LUBTOT at 600°F, Deposit Volume cm ³ × 10 ⁻⁷
10	AL-18930-L	3.21	212	9,604
16	AL-18986-L	2.97	248	11,591
20	AL-19528-L	3.08	>500	2,412

The results from the ATD C-4 pump wear and friction characteristics (Graphite) tests are reported in TABLES 7 and 8. All three lubricants (Nos. 10, 16, and 20) passed the C-4 pump wear test. Lubricant Nos. 10 and 16 passed the friction characteristics test, but Lubricant No. 20 was a borderline fail in slip time and midpoint friction of the C-4 friction characteristics test. The complete C-4 pump wear and friction characteristics test data are included in the Appendix.

TABLE 7. ATD C-4 Pump Wear Test

Lube No.	Lube Code	Pattern, %	Scratching	Scoring	Pitting	Burning	Discoloration	Test Result
10	AL-18930-L	100	None	None	None	None	Light	Pass
16	AL-18986-L	100	Light	None	None	None	Light	Pass
20	AL-19528-L	100	Light	None	None	None	None	Pass

TABLE 8. ATD C-4 Friction Characteristics (Graphite)

Lube No.	Lube Code	Slip Time, sec.	Midpoint Friction	Steel Plates Avg, in.	Clutch Plate Avg. in.	Pack Clearance, in.	Test Result
10	AL-18930-L	0.72	0.100	0.0004	0.0040	0.020	Pass
16	AL-18986-L	0.66	0.108	0.0002	0.0030	0.022	Pass
20	AL-19528-L	(0.76)	(0.094)	0.0003	0.0020	0.020	Fail

⁽⁾ Indicates Fail.

V. CONCLUSIONS

A. General

After evaluating the 20 selected lubricants, comparing these results with various commercial/proprietary hydraulic/power transmission tests, and discussing these data with personnel from Caterpillar and Allison Transmission Division, the results show that the MIL-L-2104 and MIL-L-21260 specification lubricants can satisfy all the manufacturers' warranty requirements and still meet the Army's ground vehicle/equipment lubrication needs. The military specification lubricants are judged to be acceptable, particularly if the TO-2 friction test is upgraded to the TO-4 sintered bronze friction test, the C-3 friction test is upgraded to the C-4 friction tests, and requirements for the C-4 copper corrosion tests, the C-4 and/or TO-3 fluoroelastomer seal tests, and C-4 or MERCON Sequence IV foam tests are added. This work also shows that it is possible to develop a multipurpose OEA-30 lubricant that can operate in the Arctic and warmer climates in hydraulic/power transmission and final drive systems of Army combat/tactical ground equipment than is currently specified in MIL-L-46167. The developed OEA-30 lubricant will aid in the logistics by removing two lubricant grades and one specification from the Qualified Products List.

B. <u>Specific</u>

- The problem area of the multipurpose hydraulic/power transmission fluids (Lubricant Nos. 1 through 6) appears to be foaming. Of the six fluids, four failed part of the foaming test.
- · For the 20 test lubricants, 8 failed part of the foam test.
- The five MIL-L-2104 lubricants (Nos. 7, 8, 9, 17, and 19) were evaluated. Of these lubricants, four failed the copper corrosion test at 150°C, while No. 8 also failed the total immersion hardness change part of the seal test, and one lubricant (No. 19) passed all physical/chemical tests and is also a qualified C-4 lubricant.

- Five lubricants (Nos. 1, 8, 10, 12, and 18) failed the C-4 seal compatibility tests.
- The two Caterpillar TO-4/TO-5 powershift transmission fluids (Lubricant Nos. 15 and 16) passed all physical and chemical tests, but Lubricant No. 16 had the highest deposits in the LUBTOT. These lubricants are not for engine usage.
- The two MIL-L-21260 preservative lubricants passed all physical and chemical tests with the
 exception of the 10W grade lubricant, which failed the Sequence IV part of the foaming test.
 There is no Sequence IV foam test in the MIL-L-21260 specification.
- Lubricants designed for only power transmission usage appear to produce a slightly higher level of transmission performance than the MIL-L-2104 lubricants because they passed all the hydraulic and power transmission tests.

VI. RECOMMENDATIONS

• The majority of the combat/tactical ground vehicle heavy-duty powershift transmissions use ATD transmissions that predominantly use bronze friction disc material. The ATD C-4 friction tests use graphite and paper friction materials for qualification. It appears that the Army is without a test to evaluate the bronze friction discs for its power transmissions. Even if the TO-4 bronze friction test is conducted, there is no correlation between this test and the performance of the bronze disc in Allison power transmissions. Therefore, it is recommended that a correlation be developed between the TO-4 bronze friction test and the C-4 paper and graphitic friction tests and/or develop a friction test for ATD transmission bronze friction material. In addition, it is recommended that a correlation be developed between the C-4 and TO-4 friction tests and the John Deere brake chatter test. Also until this correlation has been established, it is recommended that the TO-2 and C-3 friction tests be upgraded to the TO-4 and C-4 friction tests for the Army MIL-L-2104, MIL-L-21260, and MIL-L-46167 specifications.

- The MIL-L-46167 arctic lubricant specification has a maximum viscosity at -40°C of 8,800 cSt, while the OEA-30 candidate lubricants have a -40°C viscosity of 14,000 to 16,000 cSt. Therefore, it is recommended that low-temperature power transmission flowability/pumpability studies be conducted.
- It is also recommended to add a copper corrosion test to prevent copper corrosion, even though no apparent corrosion problems have been observed in the field. This test is necessary because of increased operating temperatures, and the MIL-L-2104, MIL-L-21260, and MIL-L-46167 have no copper corrosion tests in their specification. It will be necessary to add the C-4 and/or TO-3 fluoroelastomer seal tests. It is additionally recommended that the Sequence IV foam test be added to Army lubricant specifications MIL-L-2104, MIL-L-21260, and MIL-L-46167. With the addition of the above-recommended work, an OEA-30 hydraulic, power transmission and final drive lubricant can be developed for Army combat/tactical use.
- Caterpillar, Allison Transmission Division, and John Deere Co. have expressed concern about transmission/fluid drive wear because only the Army MIL-L-46167 lubricant has a transmission wear test, while MIL-L-2104 and MIL-L-21260 do not. To date, the Army lubricants have had positive results in the transmission/final drive wear area. However, with the new engine lubricant formulations becoming available to meet the 1994 heavy-duty diesel exhaust emission requirements, it appears it is necessary for the Army to conduct further research in transmission/final drive wear on the MIL-L-2104, MIL-L-21260, and MIL-L-46167 specification lubricants using the appropriate wear tests (pump wear and/or gear wear).

VII. LIST OF REFERENCES

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- Military Specification MIL-L-21260, "Lubricating Oil, Internal Combustion Engine, Preservative and Break-In."
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APPENDIX

C-4 Pump Wear and Friction Characteristics Test Data

SOUTHWEST RESEARCH INSTITUTE San Antonio, Texas

DIVISION OF AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID, TYPE C-4 WEAR TEST

Conducted for

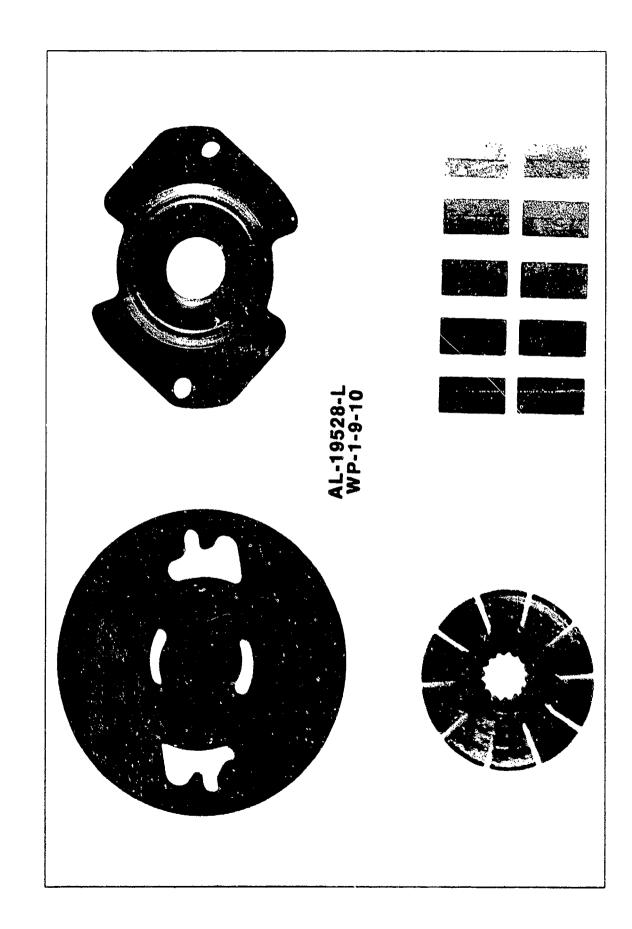
BELVOIR FUELS & LUBRICANTS RESEARCH FACILITY

AL-19528-L Test Number: WP-1-9-10

Raymond D. Townsend, Jr. Group Leader Automatic Transmission Fluids

Section |

December 5, 1990



AL-19528-L WP-1-9-10 AL-19528-L WP-1-9-10

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SOUTHWEST RESEARCH INSTITUTE San Antonio, Texas

DIVISION OF AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

ALLISON HYDRAULIC TRANSMISSION PLUID, TYPE C-4 WEAR TEST

Conducted for

BELVOIR FUELS & LUBRICANTS RESEARCH FACILITY

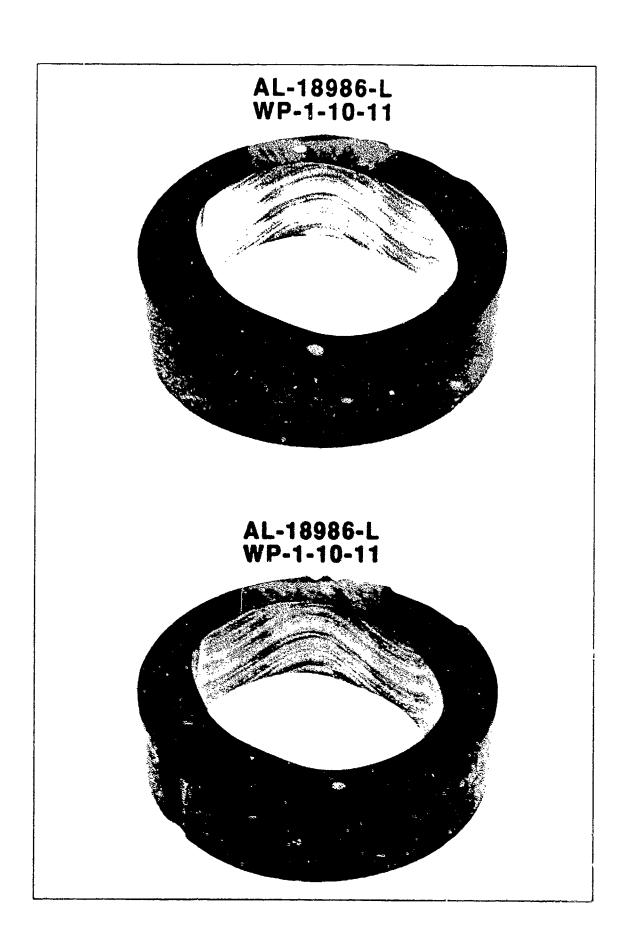
AL-18986-L Test Number: WP-1-10-11

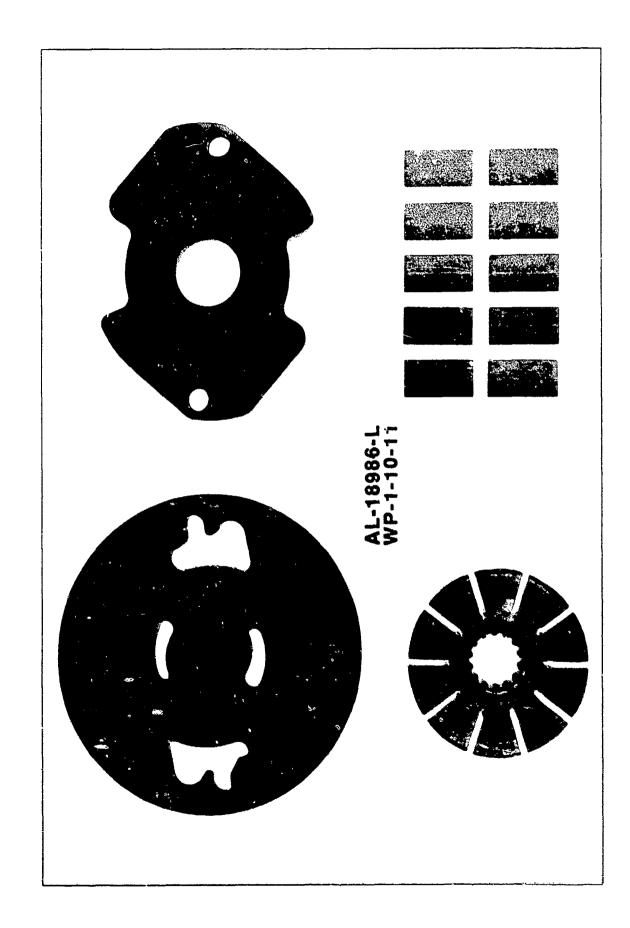
Raymond D. Townsend, Jr. Group Leader Automatic Transmission Fluids

Section

December 16, 1990

4 HEAVY-DUTY TRANSM UID SPECIFICATION	ISSION				VITT	GEN	ERAL MO	TORS
		POWER	STEERING	FUMP W	EAR TEST			
TESTING LABORATORY	: SwRI			L/	B FLUID	CODE:		
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SILICON	ICP	LIST	UNITS			1	(ATD USI	MIN
BARIUM	ICP -		ppm Al		ICP I	ppm		
BORON CALCIUM	ICD			OPPER*	ICP 1	t bu		
MAGNESIUM	ICP -		ppm 1	N*	ICP 3	ppm		
PHOSPHORUS SODIUM		==-	ppm +	run.				
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SOUTHWEST RESEARCH INSTITUTE San Antonio, Texas

DIVISION OF AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

ALLISON HYDRAULIC TRANSMISSION PLUID, TYPE C-4 WEAR TEST

Conducted for

BELVOIR FUELS & LUBRICANTS RESEARCH FACILITY

AL-18930-L Test Number: WP-1-1-13

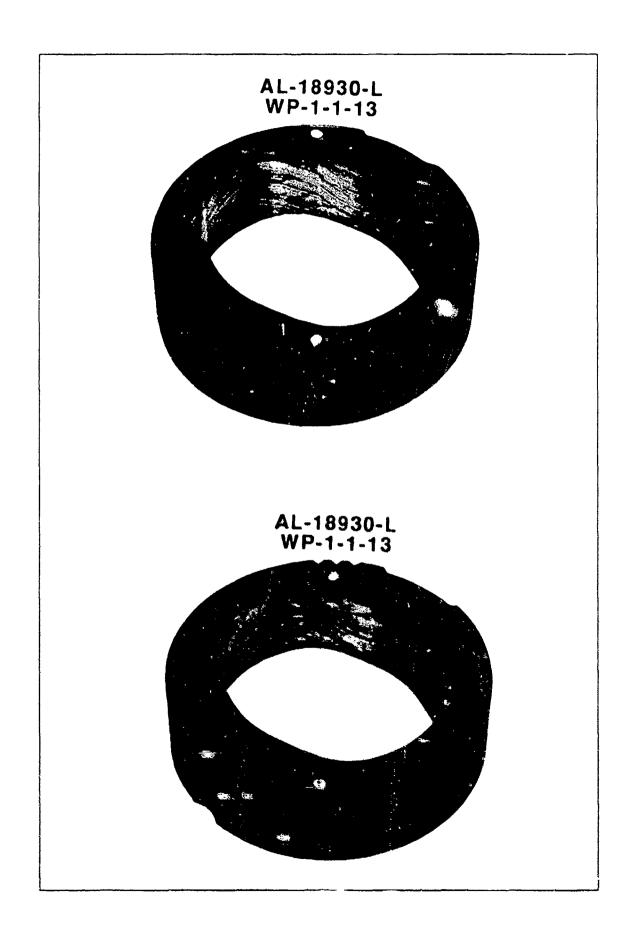
Group Leader

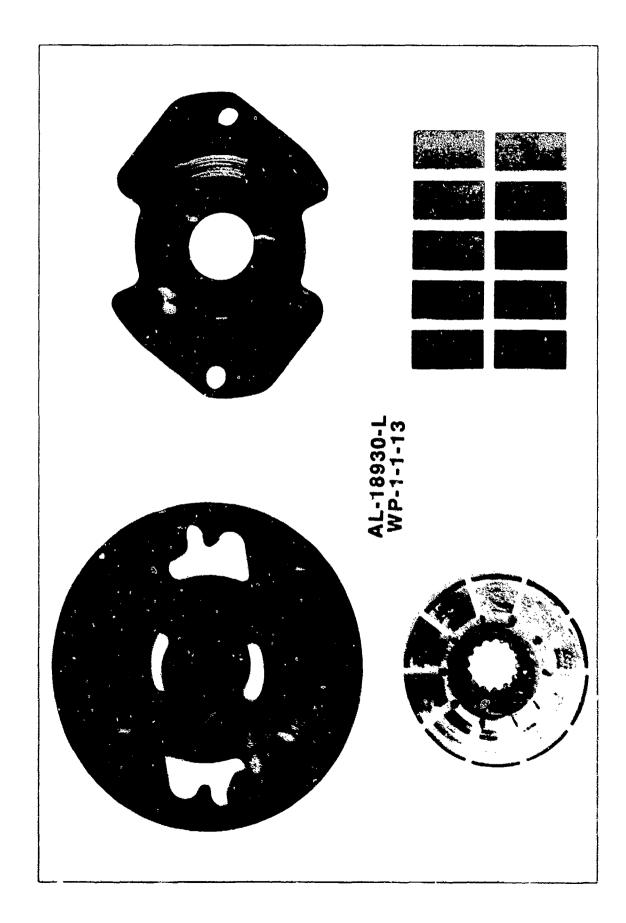
Automatic Transmission Fluids

Section

December 22, 1990

I HEAVY-DUTY TRANSMISSI UID SPECIFICATION	ION				A	G	RANSMISSI ENERAL MO	TORS
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CHEMICAL ANALYSIS								
	ICP METHOD RESUI		NITS				MAX MAX	E ONLY) MIN
BARIUM BORON	ICP			UMINUM*	ICP ICP	2 ppm		
CALCIUM	ICP	-	ppm LE	AD*	ICP	<1 ppm		
MAGNESIUM PHOSPHORUS	ICP		ppm II	N*	ICP	3 [ppn	-	
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ZINC	ICP		ppra				<u> </u>	
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DISCOLORATI	ION	<u></u>	-8.E0	ONMENT EATPS	IRON (INITIA)	L] FINAL	(ATD US	
DISCOLORATI GRINDING MA X PATTERN R	ION	100	-BEO	OMMENT S	IRON INITIA	FINAL 13	(ATD US	
DISCOLORATI GRINDING MA X PATTERN R	ON	100	-BEO	OMMENT S	IRON INITIA	FINAL 13	(ATD US	
DISCOLORATI GRINDING MA N PATTERN R	ON	100	-BEO	OMMENT S	IRON INITIA	FINAL 13	(ATD US	
DISCOLORATI GRINDING MA N PATTERN R TEST SUMMARY	ION	100	-BEO	OMMENI BATPS S	IRON O INITIA	LI FINAL	(ATD US	
DISCOLORATI GRINDING MA N PATTERN R	ION	100	-LEO PAS I	OMMENI BATPS S	IRON INITIAL DED	LI FINAL	(ATD US	
DISCOLORATI GRINDING MA N PATTERN R TEST SUMMARY	ARKS EMAINING INCLUDE CAM I	100 RING PH	PAS T OTO WITH MINIMUM 135 6196	OMMENI BATING S L HAMING	IRON INITIAL I	EAGE	(ATD US	
DISCOLORATION MATTERN R ** PATTERN R TEST SUMMARY TEMPERATU FLUID PRES	ARKS EMAINING INCLUDE CAM I	100 RING PH	PAS T OTO WITH MINIMUM 135	OMMENI EATING	IRON INITIAL I	LI FINAL 13	(ATD US	
DISCOLORATI GRINDING MA N PATTERN R TEST SUMMARY TEMPERATU FLUID PRES PLANP OUT T	INCLUDE CAN I	UNITS FEI	PAS T OTO WITH HINIMUM 135 6196 145	OMMENI BATING S L HAMING	IRON INITIA	EAGE	(ATD US	





SOUTHWEST RESEARCH INSTITUTE San Antonio, Texas

DIVISION OF AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

ALL. 30N HYDRAULIC TRANSMISSION FLUID, TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted for

BELVOIR FUELS & LUBRICANTS RESEARCH FACILITY

AL-18986-L Run Number: C7-8-83

Group Leader Automatic Transmission Fluids

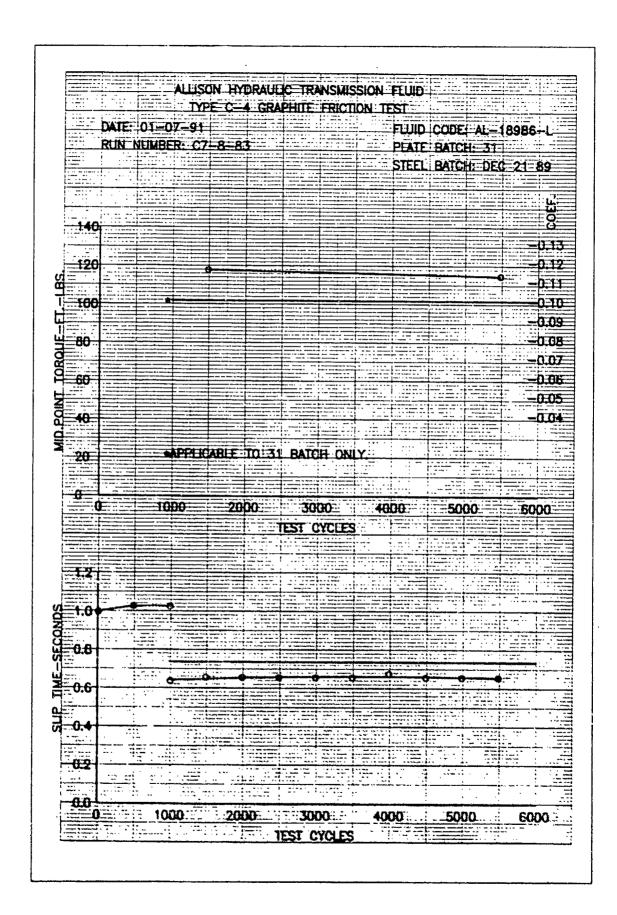
Section

January 7, 1991

4 HEAVY-DUTY TR	ANSMISSION	100 M			ALI	LISON TRAN	SMISSION I	DIVISI
UID SPECIFICATION				Bridge and the second	3-		GENERAL	
to a self-segment and a self-segment from a	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	300000000000000000000000000000000000000	And the same before	State State Contract	A	San San Chinagen	inglike till seken a t	- 45 m
	Γ	VIII. GI	RAPHITE CI	LUTCH FRI	TION	Ī		
	Ĺ		TEST RE	PORT				
TESTING LABORAT	TORY:	SwRI			SPONSOR	FLUID CODE	AL-18986	·L
TEST NUM	MBER: C7	-8-83			LAB	FLUID CODE		
	FR	ICTION PLATE	BATCH No:	31		٦		
		STEEL PLATE		Dec 21	89	_		
CHEMICAL ANALYSIS								
SILICON	ICP		ppm		ATD USE	ONLY		
	METHOD	RESULTS	UNITS		MAX	MIN		
BARIUM BORON	ICP		ppra			 		
CALCIUM	1CP		bbur bòur		 			
MAGNESIUM	ICP		ppm					
PHOSPHORUS	ICP		ppm					
SODIUM ZINC	ICP		770					
			ppm		_			
VIS @ 40 C VIS @ 100 C IRON START/THO FRICTION CHARACTE	ASTM D445 ASTM D445 ICP RISTICS	/100,30 /11.37 /29	cst cst ppm					
VIS @ 100 C IRON START/END	ASTM D445	/11.37 /29	cst ppm		RESULTS	E CUANCE	PASS	FA
VIS @ 100 C IRON START/SNO FRICTION CHARACTE	ASTM D445 ICP RISTICS	/11.37 /29 LIM 5.500 N	cst ppm TTS CHANGE		5,500 N	* CHANGE	PASS	FA
VIS @ 100 C IRON START/SNO FRICTION CHARACTE SLIP TIME (SECONDS)	ASTM D445 ICP RISTICS	/11.37 /29 LIM 5.500 N	cst ppm TS % CHANGE	0.66	5,500 N v.66	0.000	PASS X	FA
VIS @ 100 C IRON START/THO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI	ICP RISTICS IC COEFFICIEN	/11.37 /29 LIM 5,500 N 0.74 max	ppm TTS CHANGE	0.66	5,500 N v.66 0.106	0.000 4.50	PASS	FA
VIS @ 100 C IRON START/SNO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION	ICP RISTICS IC COEFFICIENT COEFFICIENT	/11.37 /29 LIM 5.500 N	ppm TTS CHANGE	0.66 0.111 0.111	5,500 N v.66 0.106 0.108	0.000 4.50 2.70	PASS	[FA
VIS @ 100 C IRON START/SNO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COE	ICP RISTICS IC COEFFICIENT COEFFICIENT	/11.37 /29 LIM 5.500 N 0.74 max 0.096 min	cst ppm ITS S CHANGE	0.66 0.111 0.111 0.145	5,500 N v.66 0.106 0.108 0.141	0.000 4.50 2.70 2.76	PASS	FA C
VIS @ 100 C IRON START/THO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COE LOW SPEED PEAK FRI	ICP RISTICS IC COEFFICIENT COEFFICIENT COTION COEFF.	/11.37 /29 LIM 5.500 N 0.74 max 0.096 min	cst ppm TTS \$ CHANGE	0.65 0.111 0.111 0.145 0.150	5,500 N v.66 0.106 0.108 0.141 0.141	0.000 4.50 2.70 2.76 6.00	PASS	
VIS @ 100 C IRON START/SNO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COE	ICP RISTICS IC COEFFICIENT COEFFICIENT COTION COEFF.	/11.37 /29 LIM 5.500 N 0.74 max 0.096 min	cst ppm ITS S CHANGE	0.66 0.111 0.111 0.145	5,500 N v.66 0.106 0.108 0.141	0.000 4.50 2.70 2.76	PASS	FA
VIS @ 100 C IRON START/THO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COE LOW SPEED PEAK FRI	ICP RISTICS IC COEFFICIENT COEFFICIENT ICTION COEFF. ED COEFF.	/11.37 /29 LIM 5.500 N 0.74 max 0.096 min	cst ppm TTS \$ CHANGE	0.65 0.111 0.111 0.145 0.150	5,500 N v.66 0.106 0.108 0.141 0.141	0.000 4.50 2.70 2.76 6.00	PASS	
VIS @ 100 C IRON START/THO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COE LOW SPEED PEAK FRI .25 SECOND LOW SPEI	ICP RISTICS IC COEFFICIENT COEFFICIENT ICTION COEFF. ED COEFF.	/11.37 /29 LIM 5.500 N 0.74 max 0.096 min	cst ppm TTS % CHANGE	0.66 0.111 0.111 0.145 0.150 0.150	5,500 N v.66 0.106 0.108 0.341 0.142 0.139	0.000 4.50 2.70 2.76 6.00 7.33		
VIS @ 100 C IRON START/THO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COE LOW SPEED PEAK FRI .25 SECOND LOW SPEI	ICP RISTICS IC COEFFICIENT COEFFICIENT ICTION COEFF. ED COEFF.	/11.37 /29 LIM 5.500 N 0.74 max 0.096 min	cst ppm ITS % CHANGE MAXIMU	0.66 0.111 0.111 0.145 0.150 0.150	5,500 N v.66 0.106 0.108 0.141 0.141 0.139	0.000 4.50 2.70 2.76 6.00 7.33	PASS	
VIS @ 100 C IRON START/THO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COE LOW SPEED PEAK FRI .25 SECOND LOW SPEI	ICP RISTICS IC COEFFICIENT COEFFICIENT EFFICIENT ECTION COEFF. ED COEFF.	/11.37 /29 LIM 5.500 N 0.74 max 0.096 min	cst ppm TTS S CHANGE MAXIMU LIMITS	0.66 0.111 0.111 0.145 0.150 0.150	5,500 N v.66 0.106 0.108 0.141 0.141 0.139 AVERAGI LIMITS	0.000 4.50 2.70 2.76 6.00 7.33		
VIS @ 100 C IRON START/THO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COE LOW SPEED PEAK FRI .25 SECOND LOW SPEI	ICP RISTICS IC COEFFICIENT COEFFICIENT ICTION COEFF. ED COEFF.	/11.37 /29 LIME 5.500 N 0.74 max 0.096 min	cst ppm TTS S CHANGE MAXIMU LIMITS	0.66 0.111 0.111 0.145 0.150 0.150 M WEAR RESULTS 0.000J	5,500 N v.66 0.106 0.109 0.141 0.142 0.139 AVERAGI	0.000 4.50 2.70 2.76 6.00 7.33 E WEAR RESULTS 0.0002		
VIS @ 100 C IRON START/THO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COE LOW SPEED PEAK FRI .25 SECOND LOW SPEI	ICP RISTICS IC COEFFICIENT COEFFICIENT EFFICIENT ICTION COEFF. ED COEFF. STEE CLUT	/11.37 /29 LIM 5.500 N 0.74 max 0.096 min	cst ppm TTS S CHANGE MAXIMU LIMITS	0.66 0.111 0.111 0.145 0.150 0.150 M WEAR RESULTS 0.000J	5,500 N v. 66 0.106 0.109 0.141 0.142 0.139 AVERAGI LIMITS	0.000 4.50 2.70 2.76 6.00 7.33		
VIS @ 100 C IRON START/THO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COE LOW SPEED PEAK FRI .25 SECOND LOW SPEI	ICP RISTICS IC COEFFICIENT COEFFICIENT EFFICIENT ICTION COEFF. ED COEFF. STEE CLUT	/11.37/29 LIM 5.500 N 0.74 max 0.096 min CL PLATES (2)	cst ppm TTS S CHANGE MAXIMU LIMITS	0.66 0.111 0.111 0.145 0.150 0.150 M WEAR RESULTS 0.000J	5,500 N v.66 0.106 0.109 0.141 0.142 0.139 AVERAGI	0.000 4.5C 2.70 2.76 6.00 7.33 E WEAR RESULTS 0.0002 0.0030		
VIS @ 100 C IRON START/THO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COE LOW SPEED PEAK FRI .25 SECOND LOW SPEI	ICP RISTICS IC COEFFICIENT COEFFICIENT EFFICIENT ICTION COEFF. ED COEFF. STEE CLUT	/11.37/29 LIM 5.500 N 0.74 max 0.096 min CL PLATES (2)	cst ppm TTS S CHANGE MAXIMU LIMITS	0.66 0.111 0.111 0.145 0.150 0.150 M WEAR RESULTS 0.000J	5,500 N u.66 0.106 0.108 0.141 0.141 0.139 AVERAGI LIMITS AFTER	0.000 4.50 2.70 2.76 6.00 7.33 E WEAR RESULTS 0.0002 0.0030 0.022	7.55 	FAI
VIS @ 100 C IRON START/THO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COE LOW SPEED PEAK FRI 25 SECOND LOW SPEE CLITCH WEAR DATA	ICP RISTICS IC COEFFICIENT COEFFICIENT EFFICIENT ICTION COEFF. ED COEFF. STEE CLUT	/11.37/29 LIM 5.500 N 0.74 max 0.096 min CL PLATES (2)	cst ppm TTS S CHANGE MAXIMU LIMITS	0.66 0.111 0.111 0.145 0.150 0.150 M WEAR RESULTS 0.000J	5,500 N v. 66 0.106 0.109 0.141 0.142 0.139 AVERAGI LIMITS	0.000 4.50 2.70 2.76 6.00 7.33 E WEAR RESULTS 0.0002 0.0030 0.022		FAI
VIS @ 100 C IRON START/*NO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COR LOW SPEED PEAK FRI 25 SECOND LOW SPEI CLITTCH WEAR DATA REFERENCE TESTS	ICP RISTICS IC COEFFICIENT COEFFICIENT EFFICIENT ICTION COEFF. ED COEFF. STEE CLUT PACK	/11.37/29 LIM 5.500 N 0.74 max 0.096 min CL PLATES (2)	CST ppm TTS SCHANGE MAXIMU LIMITS BEFORE	0.66 0.111 0.111 0.145 0.150 0.150 M WEAR RESULTS 0.0003 0.0039 0.018	5,500 N u.66 0.106 0.108 0.141 0.141 0.139 AVERAGI LIMITS AFTER	0.000 4.50 2.70 2.76 6.00 7.33 E WEAR RESULTS 0.0002 0.0030 0.022	PASS Townsend.	FAI
VIS @ 100 C IRON START/THO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COR LOW SPEED PEAK FRI 25 SECOND LOW SPEI CLIFTCH WEAR DATA REFERENCE TESTS TEST NUMBER C7-0-16	ICP RISTICS IC COEFFICIENT COEFFICIENT ICTION COEFF. ED COEFF. STEE CLUT PACK TEST DATE 05-23-30	LIM 5.500 N 0.74 max 0.096 min CH PLATES (2) CH PLATE (1) CLEARANCE	CST PPM TTS S CHANGE MAXIMU LIMITS BEFORE	0.66 0.111 0.111 0.145 0.150 0.150 M WEAR RESULTS 0.0003 0.0039 0.018	5,500 N v.66 0.106 0.108 0.141 0.141 0.139 AVERAGI LIMITS AFTER NAME:	0.000 4.50 2.70 2.76 6.00 7.33 E WEAR RESULTS 0.0002 0.0030 0.022	PASS Townsend.	[A]
VIS @ 100 C IRON START/*NO FRICTION CHARACTE SLIP TIME (SECONDS) 0.2-SECONDS DYNAMI MID-POINT FRICTION STATIC FRICTION COR LOW SPEED PEAK FRI 25 SECOND LOW SPEI CLITTCH WEAR DATA REFERENCE TESTS	ICP RISTICS IC COEFFICIENT COEFFICIENT EFFICIENT ICTION COEFF. ED COEFF. STEE CLUT PACK	/11.37/29 LIM 5.500 N 0.74 max 0.096 min CL PLATES (2) CH PLATE (1) CLEARANCE	CST PPM TTS S CHANGE MAXIMU LIMITS BEFORE	0.66 0.111 0.111 0.145 0.150 0.150 M WEAR RESULTS 0.0003 0.0039 0.018	5,500 N U.66 0.106 0.108 0.141 0.141 0.139 AVERAGI LIMITS AFTER NAME:	0.000 4.5C 2.70 2.76 6.00 7.33 E WEAR RESULTS 0.0002 0.0030 0.022	PASS Townsend.	

CLUTCH PACK IDENTIFICATION AND INSPECTION FOR FRICTION MODIFIED FLUIDS

	ary 7, 1991	Pack No	p: #205 C-4 Graphite Lot 31 Dec 21 '89 Steel's
Candidate Flo	uid I.D.:	AL-18986-L	Dec 21 07 Sceel S
Operator Name	e: <u>Mark l</u>	dolmes	
	Friction P	lates	Thickness
		Near Inner Diameter	Near Outer Diameter
Plate No.	Location	Before After Change	Before After Change
	_Top	0.0865 0.0831 0.0034	0.0857 0.0834 0.0023
2	120	0.0868 0.0829 0.0039	0,0858 0,0831 0,0027
Clockwise	240	0,0866 0,0836 0,0030	0,0859 0.0834 0,0025
	Steel Senai	ratore	Thickness
	Steel Sepa	rators Near Inner Diameter	Thickness
Place No.	Stepl Sepa		Near Outer Diameter
Place No.		Near Inner Diameter	Near Outer Diameter Before After Change
Plate No.	Location	Near Inner Diameter Before After Change	Near Outer Diameter Before After Change 0,0668 0,0566 0,0002 0,0665 0,0663 0,0002
	Location Top	Near Inner Diameter Before After Change 0.0668 0.0667 0.0001 0.0665 0.0662 0.0003 0.0680 0.0669 0.0001	Near Outer Diameter Before After Change 0.0668 0.0566 0.0002 0.0665 0.0663 0.0002 0.0665 0.0664 0.0001
1	Location Top 120	Near Inner Diameter Before After Change 0.0668 0.0667 0.0001 0.0665 0.0662 0.0003	Near Outer Diameter Before After Change 0.0668 0.0566 0.0002 0.0665 0.0663 0.0002 0.0665 0.0664 0.0001
1	Location Top 120	Near Inner Diameter Before After Change 0.0668 0.0667 0.0001 0.0665 0.0662 0.0003 0.0680 0.0669 0.0001 Average 0.0002 0.0675 0.0675 0.0000	Near Outer Diameter Before After Change 0.0668 0.0566 0.0002 0.0665 0.0663 0.0002 0.0665 0.0664 0.0001 Average 0.0002
1	Location	Near Inner Diameter Before After Change 0.0668 0.0667 0.0001 0.0665 0.0662 0.0003 0.0680 0.0669 0.0001 Average 0.0002 0.0675 0.0675 0.0000 0.0678 0.0675 0.0003	Near Outer Diameter Before After Change 0.0668 0.0566 0.0002 0.0665 0.0663 0.0002 0.0665 0.0664 0.0001 Average 0.0002 0.0676 0.0674 0.0002 0.0677 0.0674 0.0003
1 Clockwise	Location Top 120 240	Near Inner Diameter Before After Change 0.0668 0.0667 0.0001 0.0665 0.0662 0.0003 0.0680 0.0669 0.0001 Average 0.0002 0.0675 0.0675 0.0000	Near Outer Diameter Before After Change 0.0668 0.0566 0.0002 0.0665 0.0663 0.0002 0.0665 0.0664 0.0001 Average 0.0002 0.0676 0.0674 0.0002



SOUTHWEST RESEARCH INSTITUTE San Antonio, Texas

DIVISION OF AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID, TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted for

BELVOIR FUELS & LUBRICANTS RESEARCH FACILITY

AL-19528-L Run Number: C7-1-87

Group Leader

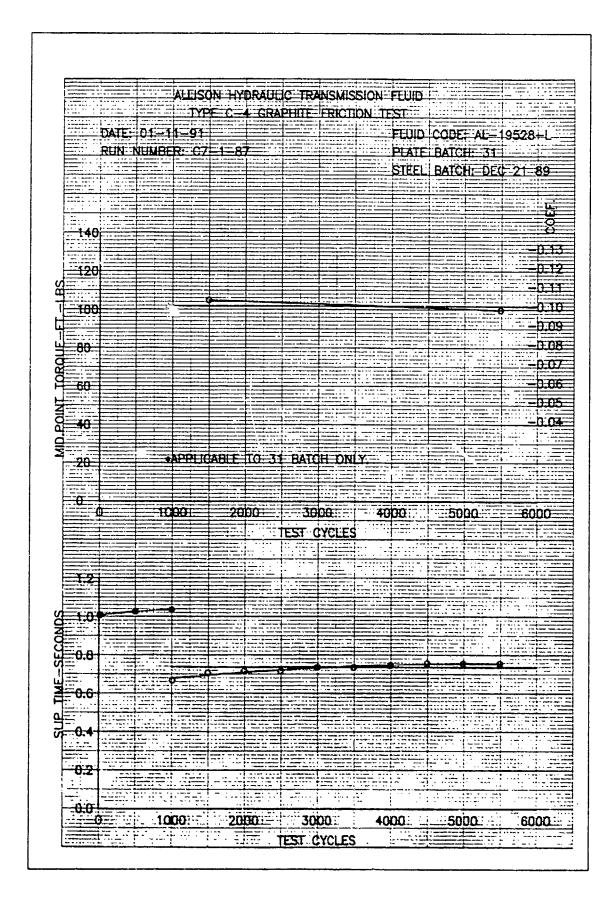
Automatic Transmission Plaids Section

January 11, 1991

VIII. GRAPHITE CLUTCH FRICTION TEST REPORT SPONSOR FLUID CODE: AL-19528-L	HEAVY-DUTY TRAN	NSMISSION	ar y			AL	LISON TRAN	ISMISSION I	ופדעונ
TESTING LABORATORY: SWRI				- Jan 18					
TEST NUMBER: C7-1-87 TEST NUMBER: C7-1-87 FRICTION PLATE BATCH No: 31 FRICTION PLATE BATCH No: 7cc 21 89 CHEMICAL ANALYSIS SILICON (CP	raspilla, kwa skwa w	1 14 6					ngaranji njeg	grand Silver in the	
TEST NUMBER: C7-1-87 TEST NUMBER: C7-1-87 FRICTION PLATE BATCH No: 31 FRICTION PLATE BATCH No: 7cc 21 89 CHEMICAL ANALYSIS SILICON (CP		٦	VW7 G	DADWEE CI	TITOU EDI	TON	`		
TEST NUMBER: C7-1-87		1	VIII. G				•		
TEST NUMBER: C7-1-87							#		
TEST NUMBER: C7-1-87	TESTING LABORATOR	DV.	Sudi			EMNEOT	ET TITO CODE	. I A: 1052	0_1
FRICTION PLATE BATCH No: 31									
CHEMICAL ANALYSIS SILICON [CP	TEST NOME	ER.				LA	FLOW CODE	<u>· I</u>	
SILICON ICP									
SILICON ICP		L	STEEL PLAT	E BATCH No:	Dec 21	89			
METHOD RESULTS UNITS	CHEMICAL ANALYSIS								
BARUM ICP Pyra	SILICON								
BORON ICP Ppra	RAPHIM		RESULTS			MAX	MON		
CALCIUM ICP PPM MAGNESIUM ICP PPM PHOSPHORUS ICP PPM PHOSPHORUS ICP PPM PM PHOSPHORUS ICP PPM PM PHOSPHORUS ICP PPM PM PHOSPHORUS ICP PPM PM							 -		
PHOSPHORUS ICP	CALCIUM								
SODIUM ICP PPm				рупа					
VIS @ 40 C						<u></u>			
VIS @ 40 C							 		
VIS @ 100 C									
IRON ICP /18 ppm			/37_23			L	 _		
LIMITS									
LIMITS	IRON						<u>!</u>		
S.500 N S.CHANGE 1.500 N S.500 N S.CHANGE	IRON START/END	ICP					<u> </u>		
0.2-SECONDS DYNAMIC COEFFICIEN	IRON START/END	ICP	/18	рра		RESULTS	<u>!</u>	PASS	FA
0.2-SECONDS DYNAMIC COEFFICIEN	IRON START/END	ICP	/18	ppm ITS	1,500 N		S CHANGE	PASS	FA
MID-POINT FRICTION COEFFICIENT 0.096 min 0.098 0.094 4.08 STATIC FRICTION COEFFICIENT 0.145 0.139 4.14 LOW SPEED FEAK FRICTION COEFF 0.145 0.139 4.14 23 SECOND LOW SPEED COEFF 0.145 0.139 4.14 CLUTCH WEAR DATA MAXIMUM WEAR AVERAGE WEAR PASS FA LIMITS RESULTS LIMITS RESULTS CLUTCH FLATE (1) 0.0034 0.0033 CLUTCH FLATE (1) 0.0022 0.0020 PACK CLEARANCE REFORE 0.015 AFTER C.020 TEST NUMBER TEST DATE TEST FLUID SIGNATURE SIG	ERON START/END FRICTION CHARACTERIS	ICP	/18 LIM 5,500 N	ppm ITS % CHANGE	 	5,500 N		PASS	
STATIC FRICTION COEFFICIENT 0.145 0.139 4.14 LOW SPEED PEAK FRICTION COEFF 0.145 0.139 4.14 23 SECOND LOW SPEED COEFF 0.145 0.139 4.14 CLUTCH WEAR DATA MAXIMUM WEAR AVERAGE WEAR PASS FA	ERON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS)	ICP STICS	5,500 N 0.74 ma)	ppm ITS % CHANGE	0.71	5,500 N 0.76	7.04	PASS	
CLUTCH WEAR DATA	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC	ICP STICS COEFFICIEN	5,500 N 0.74 may	ppm	0.71	5,500 N 0.76 0.083	7.04	PASS	
### AVERAGE WEAR PASS FA LIMITS RESULTS LIMITS RESULTS	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION CO	ICP STICS COEFFICIEN DEFFICIENT	5,500 N 0.74 may	ppm	0.71 0.097 0.098	5,500 N 0,76 0,083 0,094	7.04 14.43 4.08	PASS	
CLUTCH WEAR DATA MAXIMUM WEAR AVERAGE WEAR PASS FA	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI	ICP STICS COEFFICIENT DEFFICIENT	5,500 N 0.74 max 0.096 min	ppm	0.71 0.097 0.098 0.145	5,500 N 0.76 0.083 0.094 0.139	7.04 14.43 4.08 4.14	PASS	
MAXIMUM WEAR AVERAGE WEAR PASS FA	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT	ICP STICS COEFFICIENT DEFFICIENT FICIENT TION COEFF	5,500 N 0.74 max 0.096 min	ppm	0.71 0.097 0.098 0.145 0.145	5,500 N 0.76 0.083 0.094 0.139 0.139	7.04 14.43 4.08 4.14 4.14	PASS	
LIMITS RESULTS LIMITS RESULTS STEEL PLATES (2) G.0004 O.0003 CLUTCH PLATE (1) O.0022 O.0020 C.0020 CLUTCH PLATE (1) O.0022 O.0020 C.0020 C.002	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT	ICP STICS COEFFICIENT DEFFICIENT FICIENT TION COEFF	5,500 N 0.74 max 0.096 min	ppm	0.71 0.097 0.098 0.145 0.145	5,500 N 0.76 0.083 0.094 0.139 0.139	7.04 14.43 4.08 4.14 4.14	PASS	
LIMITS RESULTS LIMITS RESULTS STEEL PLATES (2) G.0004 0.0003 CLUTCH PLATE (1) 0.0022 0.0020 CLUTCH PLATE (1) 0.0022 0.0022 0.0020 CLUTCH PLATE (1) 0.0022 0.0022 0.0022 0.0022 CLUTCH PLATE (1) 0.0022 0.0022 0.0020 CLUTCH PLATE (1) 0.0022 0	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT .23 SECOND LOW SPEED	ICP STICS COEFFICIENT DEFFICIENT FICIENT TION COEFF	5,500 N 0.74 max 0.096 min	ppm	0.71 0.097 0.098 0.145 0.145	5,500 N 0.76 0.083 0.094 0.139 0.139	7.04 14.43 4.08 4.14 4.14	PASS	
STEEL PLATES (2)	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT .23 SECOND LOW SPEED	ICP STICS COEFFICIENT DEFFICIENT FICIENT TION COEFF	5,500 N 0.74 max 0.096 min	ppm	0.71 0.097 0.098 0.145 0.145	5,500 N 0.76 0.083 0.094 0.139 0.139 0.139	7.04 14.43 4.08 4.14 4.14		
CLUTCH PLATE (1) 0.0022 0.0020 PACK CLEARANCE SEFORE 0.015 AFTER C.020 REFFERENCE TESTS NAME: Raymond 0. Townsend, Jr. TEST NUMBER TEST DATE TEST FLUID SIGNATURE SIGN	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT .23 SECOND LOW SPEED	ICP STICS COEFFICIENT DEFFICIENT FICIENT TION COEFF	5,500 N 0.74 max 0.096 min	# CHANGE	0.71 0.097 0.098 0.145 0.145 0.145	5,500 N 0.76 0.083 0.094 0.139 0.139 0.139	7.04 14.43 4.08 4.14 4.14 4.14		
PACK CLEARANCE SEFORE 0.015 AFTER 0.020 REFERENCE TESTS NAME: Saymond D. Townsend, Jr. TEST NUMBER TEST DATE TEST FLUID SIGNATURE C1-0-29 06-21-90 00A-FASS-L C1-0-75 12-18-90 D0A-PASS-L C7-0-75 12-1	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT .23 SECOND LOW SPEED	ICP STICS COEFFICIENT DEFFICIENT FICIENT FION COEFF.	0.096 min	# CHANGE	0.71 0.097 0.098 0.145 0.145 0.145	5,500 N 0.76 0.083 0.094 0.139 0.139 0.139	7.04 14.43 4.08 4.14 4.14 4.14		
######################################	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT .23 SECOND LOW SPEED	COEFFICIENT FICIENT FI	0.096 mtm	S CHANGE MAXIMU LIMITS	0.71 0.097 0.098 0.145 0.145 0.145 RESULTS	5,500 N 0.76 0.083 0.094 0.139 0.139 0.139 Q.139	7.04 14.43 4.08 4.14 4.14 4.14 E WEAR		
### RAYTONS D. Townsend, Jr. TEST NUMBER TEST DATE TEST FLUID SIGNATURE SIGNATU	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT .23 SECOND LOW SPEED	COEFFICIENT FICIENT FICIENT FICIENT FICIENT FICIENT COEFF.	0.096 min	S CHANGE MAXIMU LIMITS	0.71 0.097 0.098 0.145 0.145 0.145 P.145	5,500 N 0.76 0.083 0.094 0.139 0.139 0.139 4VERAGE	7.04 14.43 4.08 4.14 4.14 4.14 EWEAR RESULTS 0.003		
NAME: Raymond D. Townsend, Jr.	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT .23 SECOND LOW SPEED	COEFFICIENT FICIENT FICIENT FICIENT FICIENT FICIENT COEFF.	0.096 min	# CHANGE	0.71 0.097 0.098 0.145 0.145 0.145 0.145 0.145 0.0034	5,500 N 0.76 0.083 0.094 0.139 0.139 0.139 1.139 AVERAGE LIMITS	7.04 14.43 4.08 4.14 4.14 4.14 E WEAR RESULTS 0.0003		
TEST NUMBER TEST DATE TEST FLUID SIGNATURE S	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT .23 SECOND LOW SPEED CLUTCH WEAR DATA	COEFFICIENT FICIENT FICIENT FICIENT FICIENT FICIENT COEFF.	0.096 min	# CHANGE	0.71 0.097 0.098 0.145 0.145 0.145 0.145 0.145 0.0034	5,500 N 0.76 0.083 0.094 0.139 0.139 0.139 1.139 AVERAGE LIMITS	7.04 14.43 4.08 4.14 4.14 4.14 E WEAR RESULTS 0.0003		
C7-0-29	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT .23 SECOND LOW SPEED CLUTCH WEAR DATA	COEFFICIENT FICIENT FICIENT FICIENT FICIENT FICIENT COEFF.	0.096 min	# CHANGE	0.71 0.097 0.098 0.145 0.145 0.145 0.145 0.145 0.0034	5,500 N 0.76 0.083 0.094 0.139 0.139 0.139 4.139 AVERAGE LIMITS AFTER	7.04 14.43 4.08 4.14 4.14 4.14 RESULTS 0.003 0.0020 6.0020		
C7-0-70 12-06-90 COA-PASS-L TITLE: Spur Leader (77-0-75 12-16-90 COA-PASS-L	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT .23 SECOND LOW SPEED CLUTCH WEAR DATA	COEFFICIENT FICIENT FICIENT FICIENT FICIENT FICIENT COEFF.	0.096 min	# CHANGE	0.71 0.097 0.098 0.145 0.145 0.145 0.145 0.145 0.0034	5,500 N 0.76 0.083 0.094 0.139 0.139 0.139 4.139 AVERAGE LIMITS AFTER	7.04 14.43 4.08 4.14 4.14 4.14 RESULTS 0.003 0.0020 6.0020		
(7-0-75 12-16-90 00A-PASS-L	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT 23 SECOND LOW SPEED CLUTCH WEAR DATA REPERENCE TESTS	COEFFICIENT FICIENT FICIENT FICIENT COEFF. STEE CLUT PACK	0.096 min 0.18 LIM 5,500 N 0.74 ma) 0.096 min	MAXIMU LIMITS REFORE	0.71 0.097 0.098 0.145 0.145 0.145 0.145 0.0034 0.0034	5,500 N 0.76 0.083 0.094 0.139 0.139 0.139 Q.139 LIMITS AFTER	7.04 14.43 4.08 4.14 4.14 4.14 RESULTS 0.003 0.0020 6.0020		
1 (191	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT 23 SECOND LOW SPEED CLUTCH WEAR DATA REFERENCE TESTS TEST NUMBER TI C1-2-29 C	COEFFICIENT FICIENT FICIENT FICIENT FOR COEFF. STEI CLUT PACK EST DATE 12-21-90	0.096 min	MAXIMU LIMITS EEFORE	0.71 0.097 0.098 0.145 0.145 0.145 0.145 0.0034 0.0034	5,500 N 0.76 0.083 0.094 0.139 0.139 0.139 0.139 AVERAGE LIMITS AFTER	7.04 14.43 4.08 4.14 4.14 4.14 A.14 RESULTS 0.003 0.0020 C.0020	Mass Commercia	
I NATURE I MINISTER I (BLE-WEEL) I INCHES INCHES IN CONTRACT I SECURE IN CONTRACT I CONTRACT I CONTRACT I CONTRACT I	IRON START/END FRICTION CHARACTERIS SLIP TIME (SECONDS) 0.2-SECONDS DYNAMIC MID-POINT FRICTION COEFI LOW SPEED PEAK FRICT .23 SECOND LOW SPEED CLUTCH WEAR DATA REFERENCE TESTS TEST NUMBER TI LI-0-29 0 CL-0-70 1	COEFFICIENT FICIENT FICIENT FICIENT FICIENT FOR COEFF. STEI CLUT PACK EST DATE 16-21-90 12-64-90	0.096 min 0.096	MAXIMU LIMITS BEFORE	0.71 0.097 0.098 0.145 0.145 0.145 0.145 0.0034 0.0034	5,500 N 0.76 0.083 0.094 0.139 0.139 0.139 0.139 AVERAGE LIMITS AFTER	7.04 14.43 4.08 4.14 4.14 4.14 A.14 RESULTS 0.003 0.0020 C.0020	Mass Commercia	

CLUTCH PACK IDENTIFICATION AND INSPECTION FOR FRICTION MODIFIED FLUIDS

Date: <u>Janu</u>	ary 11, 1991	Pack No	: #289 C-4 Graphite Lot 31
Candidate Fl	uid I.D.:	AL-19528-L	Rec 21 '89 Steel's
Operator Nam	e: <u>Mark</u> l	Holmes	
	Friction P	lates	Thickness
_		Near Inner Diameter	Near Outer Diameter
Plate No.	Location	Before After Change	Before After Change
	Top	0,0867 0,0847 0,0020	0,0863 0,0845 0,0018
2	120	0.0868 0.0847 0.6:21	0,0867 0,0845 0,0022
Clockwise	240	0.0868 0.0846 0.0022	0.0861 0.0845 0.0016
	C2-13-5		
	Steel Separ	Near Inner Diameter	Thickness
Plate No.	location		Near Outer Diameter
	Location	Eafore After Change	Before After Change
	Top	0.0683 0.0679 0.0004	0.0679 0.0678 0.0001
1	120	0,0681 0,0681 0,0060	0.0684 0.0680 0.0004
Clockwise	240	0.0680 0.0676 0.0004	0.0681 0.0679 0.0002
		Average 0.0003	Average 0.0002
	Top	0.0688 0.0684 0.0004	0.0685 0.0682 0.0003
3	120	0.0682 0.0680 0.0002	0.0682 0.0680 0.0002
Clockwise	<u> </u>	0.0622 0.0681 0.0001	0.0685 0.0680 0.0005
		Average 0.0002	Average 0.0003



SOUTHWEST RESEARCH INSTITUTE San Antonio, Texas

DIVISION OF AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID, TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted for

BELVOIR FUELS & LUBRICANTS RESEARCH PACILITY

AL-18930-L Run Number: C7-2-88

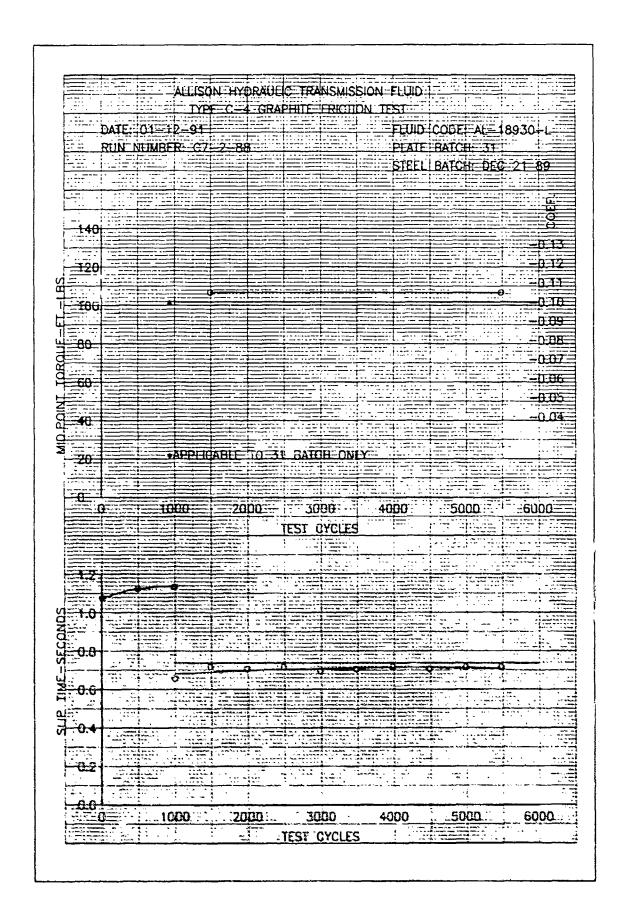
> Rayword D. Toursend, Jr. Group Leader Automatic Transmission Plyids Section

January 12, 1991

4 HEAVY-DUTY TO JUID SPECIFICATION	N				AL		NSMISSION DI GENERAL M
	11					<u> </u>	
		VIII. G	TEST RI	LUTCH FRIC	CTION		
							
TESTING LABOR		SWRI C7-2-88				FLUID CODE	
TEST NU	MBER:	L/-2-00			LA	FLUID CODE	::
	F	RICTION PLAT		31			
	Ļ	STEEL PLAT	BATCH No:	Dec 21 8	9		
CHEMICAL ANALYSI	rs e						
SILICON	ICP		pom		ATD US		
BARIUM	ICP	RESULTS	ppre		MAX	MIN	
BORON	ICP		pp ro				
CALCIUM	ICP		ppra				
MAGNESIUM PHOSPHORUS	ICP ICP		277 D		 	 	
SODIUM	ICP		ppra				
ZINC	ICP		ppm				
V13 @ 40 C	ASTM D445	/44.61	cst				
VIS @ 100 C	ASTM D445	/8.45	CRT			L	
		5,500 N	ITS S CHANGE	1,500 N	RESULTS 5,500 N	S CHANGE	PASS
SLIP TIME (SECOND	5)	0.74		0.72	0.72	0.00	I.
0.2-SECONDS DYNA	LIC COEFFICIE			0.097	0.093	4.12	
MID-POINT FRICTION	N COEFFICIENT	0.096 min	·	0.100	0.100	0.000	
STATIC FRICTION CO	DEFFICIENT	0.000		0.133	0.131	0.150	
LOW SPEED PEAK FI	AICTION COEFF			0.126	0.126	0.000	
.25 SECOND LOW SP	EED COEFF.	1		0,126	0.125	0,000	
				<u> </u>		7 2.489	_
CLUTCH WEAR DAT	_				,		,,
			LIMITS	M WEAR RESULTS	AVERAG	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	PASS
	STF	EL PLATES (2)		0.0007	LIMITS	0.0004	П
	 	TCH PLATE (1)	 	0.0045		 	H
	}	CLEARANCE	}		 	0.0040	l H
	FACE		BEFORE	0.617	AFTER	0.029	U
REPERENCE TESTS							
					NAME:	Express (O. Townsend, J.
	TEST DATE	TEST FI	ריים		GNATURE/	1 Lane	MATE
TEST MILLIAGE	(6-21-9)	CCA-FASS-		34		JAN THE	CONTRACTOR OF THE PARTY OF THE
TEST NUMBER C7-0-29	1 (5-41-2)					office so	2000
07-0-29 07-0-70	12-04-45	CCA-PASS-			TITLE.	With 18	+
07-0-29					DATE:	7	

CLUTCH PACK IDENTIFICATION AND INSPECTION FOR FRICTION MODIFIED FLUIDS

Date: <u>Janu</u>	ary 12, 1991		Pack No:	#290 C-4 Graphite Lot 31 Dec 21 '89 Steel's
Candidate Fl	uid I.D.:	AL-18930-L		Dec 21 Of Steel 5
Operator Nam	e: <u>Mark</u>	dolmes		
	Friction P	lates		Thickness
		Near Inner Dia	meter	Near Outer Diameter
Plate No.	Location	Before After	Change	Before After Change
	Top	0,0881 0,0836	0,0045	0.0871 0.0832 0.0039
2	120_	0.0877 0.0835	0,0042	0,0873 0,0833 0,0040
Clockwise	240	0.0879 0.0836	0.0043	0,0869 0,0836 0,0033
		Average	0.0043	Average 0.0037
	Steel Sepa	rators		Thickness
		Near Inner Dia	ameter	Near Outer Diameter
Place No.	Location	Before After	Change	Before After Change
	Top	0,0678_0,0675	0.0003	0.0679 0.0675 0.0004
1	120	0.0683 0.0676		0,0679 0,0676 0,0003
Clockwise	240	0.0676 0.0672		0.0678 0.0676 0.0002
		Average		Average 0.0003
	Top	0.0681 0.0675	0.0006	0.0679 0.0675 0.0004
3	120	0.0676 0.0673		0.0679 0.0673 0.0004
Clockvise	240	0.0678 0.0674	0.0004	0.0676 0.0675 0.0001
PIOCKALZE	494			
		Average	U. UUU4	Average 0.0004



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101ST AIRBORNE DIV (AASLT)		MILII ARY TRAFFIC MGM COMMAND	
ATTN: AFZB-KE-J	1	ATTN: MT-SA	
AFSB-KE-DMMC	1	WASHINGTON DC 20315	
FORT CAMPBELL KY 42223			
		CDR	
CDR		COMBINED ARMS COMBAT DEV ACTY	
US ARMY QUARTERMASTER SCHOOL		ATTN: ATZL-CAT-E	
ATTN: ATSM-CDM (MR C PARENT)	1	ATZL-CAT-A	٠
ATSM-PWD (LTC GIBBONS)	1	FORT LEAVENWORTH KS 66027-5300	
FORT LEE VA 23801	_		
		CDR	
CDR		US ARMY ORDNANCE CENTER & SCHCOL	
US ARMY COMBINED ARMS & SUPPT CM	/m	ATTN: ATSL-CD-CS	
AND FT LEE		ABERDEEN PROVING GROUND MD	•
ATIN: ATCL-CD	1	21005	
ATICL-MS	1	21005	
FORT LEE VA 23801-6000	1	CDR	
PORT LED VA 23601-0000		US ARMY WESTERN COMMAND	
CDB		ATTN: APLG-TR	
CDR			•
US ARMY FIELD ARTILLERY SCHOOL		FORT SCHAFTER HI 96858-5100	
ATTN: ATSF-CD	1	ania	
FORT SILL OK 73503-5600		CINC	
		US SPECIAL OPERATIONS COMMAND	
CDR		ATIN: SOJ4-P	
US ARMY TRANSPORTATION SCHOOL		MACDILL AFB FL 33608	
ATTN: ATSP-CD-MS	1		
FORT EUSTIS VA 23604-5000		CDR	
		US CENTRAL COMMAND	
CDR		ATIN: CINCCEN/CC J4-L	
US ARMY INFANTRY SCHOOL		MACDILL AFB FL 33608	
ATIN: ATSH-CD-MS-M	1		
FORT BENNING GA 31905-5400		HQ, EUROPEAN COMMAND	
		ATTN: ECJ4/LU (LTC CUMBERWORTH)	1
CDR		VAIHINGEN, GE	
US ARMY AVIATION CTR & FT RUCKER		APO NEW YORK 09128	
ATTN: ATZQ-DI	1		
FORT RUCKER AL 36362			
CDR			
US ARMY ENGINEER SCHOOL			
ATTN: ATSE-CD	1		
FORT LEONARD WOOD MO 65473-5000			

Department of the Navy

CDR NAVAL AIR PROPULSION CENTER ATTN: PE-33 (MR D'ORAZIO) PE-32 (MR MANGIONE) P O BOX 7176 TRENTON NJ 06828-0176	1 1	JOINT OIL ANALYSIS PROGRAM - TECHNICAL SUPPORT CENTER BLDG 780 NAVAL AIR STATION PENSACOLA FL 32508-5300	1
CDR DAVID TAYLOR RESEARCH CENTER ATTN: CODE 2830 (MR SINGERMAN) CODE 2832 (MS BIEDERICH) CODE 2759 (MR STRUCKO) ANNAPOLIS MD 21402-5067 OFFICE OF CHIEF OF NAVAL RESEARCH	1 1 1	CDR NAVAL AIR SYSTEMS COMMAND ATIN: CODE 53632F (MR MEARNS) WASHINGTON DC 20361-5360 CDR NAVAL RESEARCH LABORATORY ATIN: CODE 6180 WASHINGTON DC 20375-5000	1
ATTN: OCNR-12E (DR ROBERTS) ARLINGTON VA 22217-5000 C'DR NAVAL AIR ENGR CENTER ATTN: CODE 92727 LAKEHURST NJ 08733	1	US MARINE CORP LIAISON ATTN: USMC-LNO (MAJ OTTO) US ARMY TANK-AUTOMOTIVE COMMAND (TACOM) WARREN MI 48397-5000	1
CDR NAVAL SEA SYSTEMS COMMAND ATTN: CODE 05M32 (MR DEMPSEY) WASHINGTON DC 20362-5101	1	CDR NAVAL SHIP SYSTEMS ENGINEERING STATION ATTN: CODE 053C PHILADELPHIA PA 19112-5083	1
CDR NAVAL FACILITIES ENGR CENTER ATTN: CODE 1202B (MR BURRIS) 200 STOVAL STREET ALEXANDRIA VA 22322	1	DEPUTY COMMANDING GENERAL USMC RD&A COMMAND ATTN: PM GND WEAPONS (CB6T), LTC VARELLA SSEA (LTC PHILLIPS) QUANTICO VA 22134-5080	1
CDR NAVAL PETROLEUM OFFICE ATTN: CODE 40 (MR LONG) CAMERON STATION ALEXANDRIA VA 22304-6180	1	COMMANDING GENERAL USMC RD&A CMD ATTN: CODE SSCMT WASHINGTON DC 20380-0001	1
DEPARTMENT OF THE NAVY HQ, US MARINE CORPS ATIN: LPP-2 (MAJ TALLERI) WASHINGTON DC 20380	1	H&S BATTALION ATTN: MCCDE (CODE WF12E1) WARFIGHTING CENTER GUANTICO VA 22134-5010	1
OFFICE OF THE CNO ATTN: OP-TUD DEPT OF NAVY WASHINGTON DC 20130	1		

Department of the Air Force

HQ, US AIR FORCE ATTN: LEYSF WASHINGTON DC 20330	1	CDR US AIR FORCE WRIGHT AERO LAB ATTN: POSF (MR DELANEY) POSL (DR DAYTON)	1		
CDR SAN ANTONIO AIR LOGISTICS CTR ATTN: SAALC/SFT (MR MAKRIS) SAALC/LDPE (MR ELLIOT)	1 1	MLSE (MS REID) MLBT (MR SNYDER) WRIGHT-PATTERSON AFB OH 45433-6563	1		
CDR WARNER ROBINS AIR LOGISTIC CTR ATTN: WRALC/LVR-1 (MR PERAZZOLA)	1	CDR DET 29 ATTN: SA-ALC/SFM CAMERON STATION ALEXANDRIA VA 22304-6179	1		
ROBINS AIR FORCE BASE GA 31098 615 SMSQ/LGTV (MMEP) BLDG 100 ROOM 234 EGLIN AIR FORCE BASE FL 32542-5000	1	CDR USAF 3902 TRANSPORTATION SQUADRON ATTN: LGTVP (MR VAUGHN) OFFUTT AIR FORCE BASE NE 68113	1		
Other Organizations					
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION LEWIS RESEARCH CENTER CLEVELAND OH 44135	1	DEPARTMENT OF ENERGY CE-151, ATTN: MR JOHN RUSSELL 1000 INDEPENDENCE AVE, SW WASHINGTON DC 20585	1		
DEPT OF TRANSPORTATION FEDERAL AVIATION ADMINISTRATION AWS-110 800 INDEPENDENCE AVE, SW WASHINGTON DC 20590	1	ENVIRONMENTAL PROTECTION AGENCY AIR POLLUTION CONTROL 2565 PLYMOUTH ROAD ANN ARBOR MI 48105	1		